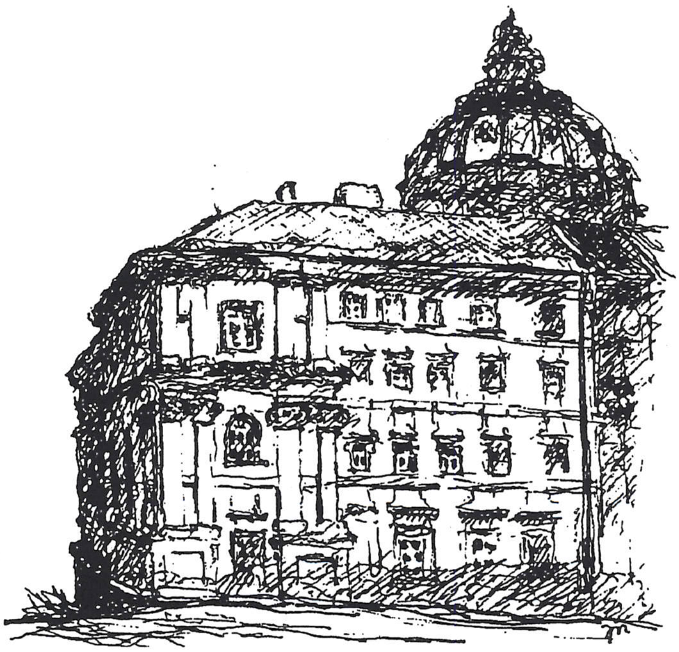
RAMSEY CLASSES AND BEYOND

JAROSLAV NEŠETŘIL
CHARLES UNIVERSITY
PRAGUE

RaTLoCC
BERTINORO II. - 2018

RAMSEY CLASSES AND BEYOND

JAROSLAV NEŠETŘIL
CHARLES UNIVERSITY
PRAGUE
&
DAVID EVANS
LONDON
JAN HUBIČKA
PRAGUE



RaTLoCC
BERTINORO II - 2018

GRAPH RAMSEY THEOREM $\boxed{\text{GRT}}$

EVERY LARGE GRAPH G $(|G| \geqslant N)$

CONTAINS:

EITHER LARGE CLIQUE OR LARGE INDEPENDENT SET

$\omega(G) \geqslant n$ $\alpha(G) \geqslant n$.

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CONTAINS:

EITHER LARGE CLIQUE OR LARGE INDEPENDENT SET

$$\omega(G) \geqslant n \qquad \alpha(G) \geqslant n.$$

$\boxed{\text{GRT}}$

FOR EVERY PARTITION $\binom{[N]}{2} = a_1 \cup \ldots \cup a_k$

THERE EXISTS $Y \subseteq [N] = \{1, 2, \ldots, N\}$, i_0

SUCH THAT $|Y| = n$

$$\binom{Y}{2} \subseteq a_{i_0}.$$

$$N \longrightarrow (n)^2_k$$

ERDÖS-RADO PARTITION ARROW

FINITE RAMSEY THEOREM | FRT

$\forall p, k, n \quad \exists N:$

FOR EVERY PARTITION $\binom{[N]}{p} = a_1 \cup \ldots \cup a_k$

THERE EXISTS $Y \subseteq [N]$, i_0 SUCH THAT

$$\binom{Y}{p} \subseteq a_{i_0}.$$

$$N \longrightarrow (n)^p_k .$$

OTHER EARLY EXAMPLES

(PIDGEON HOLE $p=1$)

VAN DER WAERDEN

SCHUR

HILBERT

OTHER EARLY EXAMPLES

(PIDGEON HOLE $p=1$)

VAN DER WAERDEN

SCHUR

HILBERT

---

60 – 70ies

COMBINATORIAL CUBES — HALES-JEWETT, GRAHAM-ROTHSCHILD

(m,p,c) SETS — (RADO CONJECTURE) DEUBER, LEEB

FINITE VECTOR SPACES — (ROTA CONJECTURE) GRAHAM, LEEB, ROTHSCHILD

K_k-FREE GRAPHS — (ERDÖS, GALVIN, HAJNAL) N. RÖDL

DEFINITION OF $\boxed{\text{RAMSEY CLASS}}$

(LEEB, N., RÖDL)

$\mathcal{K}$ CLASS OF STRUCTURES + SUBOBJECTS (EMBEDDINGS)

$A, B \in \mathcal{K}$ $\quad \binom{B}{A}$ = ALL SUBOBJECTS OF B ISOMORPHIC TO A

INTERESTING HISTORY

$\binom{n}{k}$ A. ETTINGHAUSEN

MENDEL

AABAB

$\binom{X}{k}$

$\binom{B}{A}$

4''

ANDREAS VON ETTINGHAUSEN:

DIE KOMBINATORISCHE ANALYSIS
ALS
VORBEREITUNGSLEHRE ZUM STUDIUM
DER
THEORETISCHEN HÖHEREN MATHEMATIK

1826

4 III

Die combinatorische Analysis

als

Vorbereitungslehre zum Studium

der

theoretischen höhern Mathematik,

dargestellt

von

Andreas v. Ettingshausen,

Professor der höhern Mathematik an der k. k. Universität zu Wien.

Wien, 1826.

Druck und Verlag von J. B. Wallishausser.

4 IV

Versuche

über

Pflanzen-Hybriden,

von

Gregor Mendel.

(Separatabdruck aus dem IV. Bande der Verhandlungen des naturforschenden Vereines.)

Im Verlage des Vereines.

Brünn, 1866.

Aus Georg Gastl's Buchdruckerei, Postgasse Nr. 446.

HELENA NEŠETŘILOVÁ, J.N.:

MATHEMATICS OF MENDEL,

MENDELIANUM, FOLIA MENDELIANA
53, 1-2 (2017), 5-22.

DEFINITION OF $\boxed{\text{RAMSEY CLASS}}$

(LEEB, N., RÖDL)

$\mathcal{K}$ CLASS OF STRUCTURES + SUBOBJECTS (EMBEDDINGS)

$A, B \in \mathcal{K}$ $\quad \binom{B}{A}$ = ALL SUBOBJECTS OF B ISOMORPHIC TO A

$\mathcal{K}$ IS A $\boxed{\text{RAMSEY CLASS}}$

IF

FOR EVERY $A, B \in \mathcal{K}$, $k \in \mathbb{N}$,
THERE EXISTS $C \in \mathcal{K}$ SUCH THAT

$$C \longrightarrow (B)^A_k$$

$$\equiv$$

FOR EVERY PARTITION $\binom{C}{A} = \mathcal{a}_1 \cup \ldots \cup \mathcal{a}_k$
THERE EXISTS $B' \in \binom{C}{B}$, i_0
SUCH THAT $\binom{B'}{A} \subseteq \mathcal{a}_{i_0}$.

A GENERAL COMMENT

$$C \longrightarrow (B)^A_2 \Longleftrightarrow \chi(\langle A,B,C\rangle) > 2$$

$$\langle A,B,C\rangle = (X, \mathcal{M})$$

$$X = \binom{C}{A}$$

$$M \in \mathcal{M} \Longleftrightarrow \exists\, B' \in \binom{C}{B}$$

$$M = \binom{B'}{A}$$

WHAT ARE TOOLS FOR HIGH CHROMATIC #

?

WHAT ARE TOOLS FOR HIGH CHROMATIC #
?

- PIDGEONHOLE
- PRODUCTS
- DENSITY $\left(\chi \geq \frac{|X|}{\alpha}\right)$
- EIGENVALUES
- ALG. GEOMETRY (KNESER-LOVÁSZ)
- PROBABILISTIC

⋮

WHAT ARE TOOLS FOR HIGH CHROMATIC #
?

- PIDGEONHOLE
- PRODUCTS
- DENSITY $\left(\alpha \geq \frac{|X|}{\alpha}\right)$
- EIGENVALUES
- ALG. GEOMETRY (KNESER-LOVÁSZ)

$\vdots$

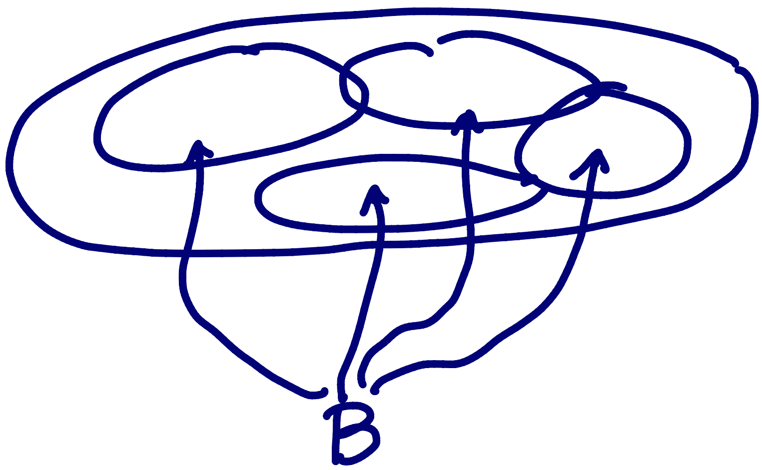
- ULTRAFILTERS

$(X, \mathcal{U})$ ULTRAFILTER

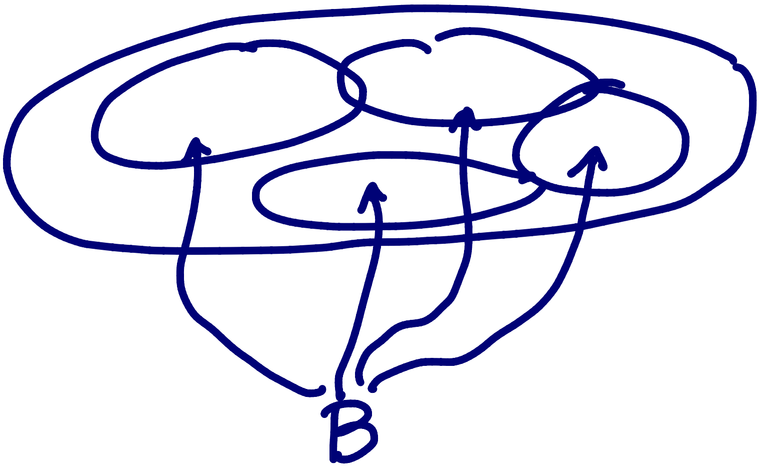
$\Downarrow$

$$\chi(X, \mathcal{U}) > 2$$

WHY NOT (RANDOM) INSERTION METHOD?



WHY NOT (RANDOM) INSERTION METHOD ?

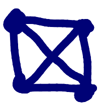


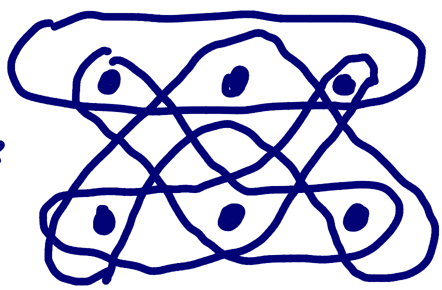
USEFULL FOR $|A| = 1$

FOR $|A| > 1$ $\langle A, B, C \rangle$

VERY STRUCTURED

$\boxed{\text{EXAMPLE}}$

A =  , B =  , C = 

$\langle A, B, C \rangle$ = 

RAMSEY CLASSES

$\parallel$

TOP OF THE LINE OF RAMSEY PROPERTIES

"ONE CAN COLOUR ANYTHING (POINTS, EDGES, ...)
IN ANY NUMBER OF COLOURS AND
YET OBTAIN ANY GIVEN OBJECT
MONOCHROMATIC"

EXAMPLES OF RAMSEY CLASSES

ARITHMETIC PROGRESSIONS ($\subseteq \mathbb{Z}$)	NO
—— ($\subseteq \mathbb{Z}^n$)	YES
GRAPHS	NO
ORDERED GRAPHS	YES
ORDERED $\triangle$-FREE	YES
ORDERED $\square$-FREE	NO

$\boxed{\text{EXAMPLES}}$ OF RAMSEY CLASSES

ARITHMETIC PROGRESSIONS	$(\subseteq \mathbb{Z})$	NO
——— " ———	$(\subseteq \mathbb{Z}^n)$	YES
GRAPHS		NO
ORDERED GRAPHS		YES
ORDERED $\triangle$-FREE		YES
ORDERED $\square$-FREE		NO

COMBINATORIAL ZOO

CHARACTERISATION OF RAMSEY CLASSES ?

I. AMALGAMATION CHARACTERIZATION

$$
\begin{tikzcd}
\text{RAMSEY} \arrow[r] & \text{AMALGAMATION} \arrow[d] \\
\text{SPECIAL CLASS} \arrow[u] & \text{ULTRAHOMOGENEOUS} \arrow[l]
\end{tikzcd}
$$

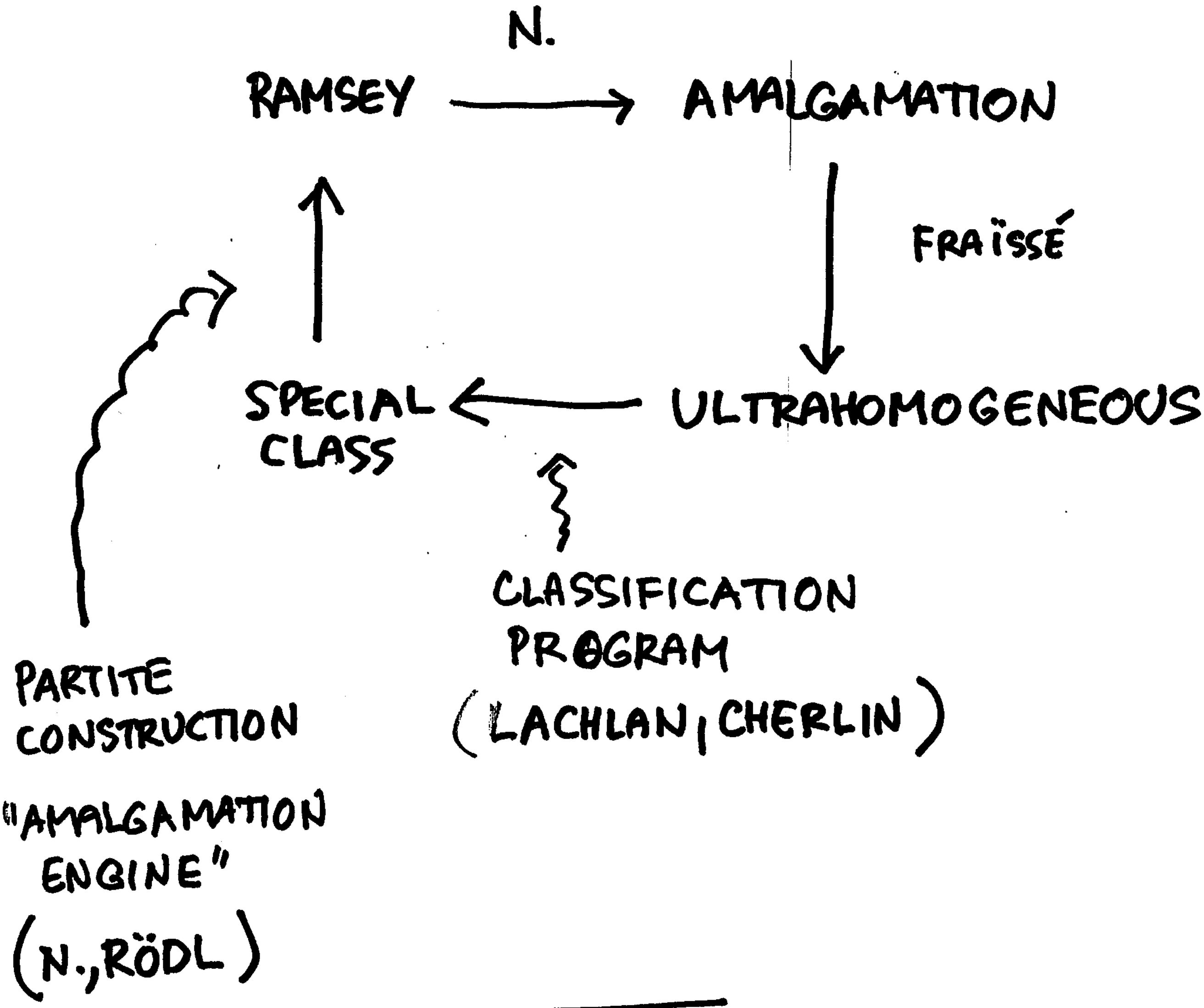
I. AMALGAMATION CHARACTERIZATION

$$\begin{tikzcd}
\text{RAMSEY} \arrow[r, "\text{N.}"] & \text{AMALGAMATION} \arrow[d, "\text{FRAÏSSÉ}"] \\
\text{SPECIAL CLASS} \arrow[u] & \text{ULTRAHOMOGENEOUS} \arrow[l]
\end{tikzcd}$$

PARTITE CONSTRUCTION
"AMALGAMATION ENGINE"
(N., RÖDL)

CLASSIFICATION PROGRAM
(LACHLAN, CHERLIN)

I. AMALGAMATION CHARACTERIZATION



$\boxed{\text{MANY EXAMPLES}}$

GRAPHS, RELATIONAL STRUCTURES, POSETS
METRIC SPACES, ...

CHARACTERIZATION OF

- ALL RAMSEY CLASSES OF GRAPHS WITH FREE ORDERING (N. 89)
- ALL RAMSEY CLASSES OF POSETS WITH LINEAR EXTENSION (N. 05)
- ALL RAMSEY CLASSES OF TOURNAMENTS WITH FREE ORDERING (N. 05)
- ALL RAMSEY CLASSES OF DIRECTED GRAPHS WITH ORDERING AND LABELING (JASINSKI, LAFLAMME, NGUYEN VAN THE, WOODROW 2013)

CHARACTERISATION OF UTRAHOMOGENEOUS (LACHLAN + WOODROW, CHERLIN)

+

COMBINATORIAL THEOREMS (N. + RÖDL)

I. AMALGAMATION CHARACTERIZATION

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\text{RAMSEY} \arrow[r] & \text{AMALGAMATION} \arrow[d] \\
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\end{tikzcd}
$$

$\boxed{\text{FREE AMALGAMATION}}$

$\boxed{\text{THM}}$ (N., RÖDL 77)

ANY CLASS $\mathcal{K}$ OF RELATIONAL STRUCTURES CLOSED ON FREE AMALGAMATION AND FREE ORDERINGS IS A RAMSEY CLASS

$\boxed{\text{THM}}$ (EVANS, HUBIČKA, N. 17)

LET L BE LANGUAGE (INVOLVING RELATION SYMBOLS AND PARTIAL FUNCTIONS).

LET $\mathcal{K}$ BE A FREE AMALGAMATION CLASS OF L-STRUCTURES. THEN $\overrightarrow{\mathcal{K}}$ IS A RAMSEY CLASS.

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$\boxed{\text{COROLLARY}}$

BOWTIE FREE GRAPHS HAVE FINITE RAMSEY EXPANSION

(FORB())

THM (EVANS, HUBIČKA, N. 17)

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COROLLARY

BOWTIE FREE GRAPHS HAVE FINITE RAMSEY EXPANSION

(FORB())

COROLLARY

STEINER SYSTEMS FORM A RAMSEY CLASS

II. TOPOLOGICAL CHARACTERISATION

$$
\begin{tikzcd}
\text{RAMSEY} \arrow[r] & \text{AMALGAMATION} \arrow[d] \\
\text{AUTOMORPHISM GROUP} & \text{ULTRAHOMOGENEOUS} \arrow[l]
\end{tikzcd}
$$

II. TOPOLOGICAL CHARACTERISATION

$$
\begin{tikzcd}
\text{RAMSEY} \arrow[r] \arrow[d, leftrightarrow] & \text{AMALGAMATION} \arrow[d] \\
\text{EXTREME AMENABILITY} & \text{ULTRAHOMOGENEOUS} \arrow[l]
\end{tikzcd}
$$

KECHRIS, PESTOV, TODORCEVIC (05)

"KPT CORRESPONDENCE

II. TOPOLOGICAL CHARACTERISATION

$$\begin{tikzcd}
\text{RAMSEY} \arrow[r] \arrow[d, leftrightarrow] & \text{AMALGAMATION} \arrow[d] \\
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KECHRIS, PESTOV, TODORCEVIC (05)

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EXTREM AMENABILITY VIA RAMSEY

(GLASNER, WEISS)

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KECHRIS, PESTOV, TODORCEVIC (05)

"KPT CORRESPONDENCE

EXTREM AMENABILITY VIA RAMSEY
(GLASNER, WEISS)

$\boxed{\text{QUEST FOR RAMSEY CLASSES}}$

III. EXPANSIONS & LIFTS

$$\begin{tikzcd}
\text{RAMSEY} \arrow[r] & \text{AMALGAMATION}^{+} \arrow[d] \\
\text{STRUCTURE}^{+} \arrow[u] & \text{ULTRAHOMOGENEOUS} \arrow[l]
\end{tikzcd}$$

III. EXPANSIONS & LIFTS

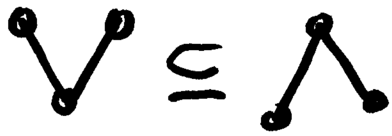
$$\begin{tikzcd} \text{RAMSEY} \arrow[r] & \text{AMALGAMATION} + \arrow[d] \\ \text{EXPANSION (LIFT)} \arrow[u] & \text{ULTRAHOMOGENEOUS} \arrow[l] \end{tikzcd}$$

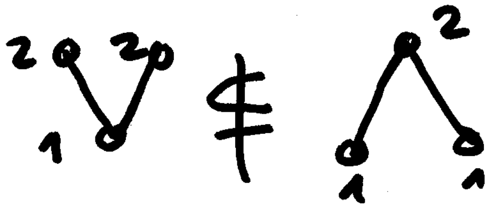
LANGUAGE | EXTENDED LANGUAGE

$$L \rightsquigarrow L \cup \begin{array}{l}\text{ADDITIONAL} \\ \text{RELATIONS} \\ \text{FUNCTIONS}\end{array}$$

EXAMPLES

BIPARTITE GRAPHS ⇝ BIPARTITE GRAPHS WITH MARKED PARTS





GRAPHS ⇝ GRAPHS WITH ORDERED VERTICES

III. EXPANSIONS & LIFTS

$$\begin{tikzcd} \text{RAMSEY} \arrow[r] & \text{AMALGAMATION +} \arrow[d] \\ \text{EXPANSION (LIFT)} \arrow[u] & \text{ULTRAHOMOGENEOUS} \arrow[l] \end{tikzcd}$$

FOR WHICH ω- CATEGORICAL STRUCTURE

THE AGE HAS FINITE
PRECOMPACT

RAMSEY EXPANSION ?

(BERTINORO QUESTION 11
BODIRSKY, VAN THE, N.
PINSKER, TSANKOV,)

GROUP FORMULATION

SUPPOSE G IS CLOSED, OLIGOMORPHIC PERMUTATION GROUP ON A COUNTABLE SET. DOES THERE EXIST A CLOSED, EXTREMELY AMENABLE, OLIGOMORPHIC SUBGROUP OF G ?

GROUP FORMULATION

SUPPOSE G IS CLOSED, OLIGOMORPHIC PERMUTATION GROUP ON A COUNTABLE SET. DOES THERE EXIST A CLOSED, EXTREMELY AMENABLE, OLIGOMORPHIC SUBGROUP OF G ?

NO (EVANS 16)

BUT MAXIMAL EXTREMELY AMENABLE SUBGROUPS EXIST

$\Updownarrow$

OPTIMAL RAMSEY EXPANSIONS EXIST

HRUSHOVSKI CLASSES $\mathcal{C}_F$

k- ORIENTABLE GRAPHS

+

$$k \cdot |A| - \left|E \cap \binom{A}{2}\right| \geq F(|A|)$$

FOR ALL $A \subseteq V$.

$\boxed{\text{THM}}$ (EVANS, HUBIČKA, N. 17)

1. $\mathcal{C}_F$ OLIGOMORPHIC
2. EVERY EXTREMELY AMENABLE SUBGROUP HAS INFINITELY MANY ORBITS ON $[\mathbb{N}]^2$.
3. THER EXIST REASONABLE EXPANSION OF $\mathcal{C}_F$ WHICH IS RAMSEY CLASS

POSITIVE SOLUTIONS

① FORBIDDEN SET OF IRREDUCIBLE STRUCTURES

(IRREDUCIBLE ≡ FREE AMALGAM IRREDUCIBLE)
≡ ANY PAIR OF DISTINCT POINTS COVERED

RAMSEY LIFT = ORDERING

(N., RÖDL 78)

POSITIVE SOLUTIONS

① FORBIDDEN SET OF IRREDUCIBLE STRUCTURES

(IRREDUCIBLE ≡ FREE AMALGAM IRREDUCIBLE
≡ ANY PAIR OF DISTINCT POINTS COVERED)

RAMSEY LIFT = ORDERING

(N., RÖDL 78)

② FORBIDDEN HOMOMORPHISMS FROM A FINITE SET OF CONNECTED STRUCTURES

(N. 10)

RAMSEY LIFT = ORDERING + PIECES

(NEEDED: NEW COMBINATORIAL PROOF OF CHERLIN, SHELAH, SHE)

(3) FORBIDDEN HOMOMORPHISMS FROM AN INFINITE REGULAR FAMILY $\mathcal{F}$ WHICH IS LOCALLY FINITE

RAMSEY LIFT = ORDERING + MAXIMAL

(J. HUBIČKA, N. 15)

(3) FORBIDDEN HOMOMORPHISMS FROM AN INFINITE REGULAR FAMILY $\mathcal{F}$ WHICH IS LOCALLY FINITE

RAMSEY LIFT = ORDERING + MAXIMAL

(J. HUBIČKA, N. 15)

$\boxed{\text{EXAMPLE}}$ $\mathrm{FORB}_{\mathrm{HOM}}$ ()

3 FORBIDDEN HOMOMORPHISMS FROM AN INFINITE REGULAR FAMILY $\mathcal{F}$ WHICH IS LOCALLY FINITE

RAMSEY LIFT = ORDERING + MAXIMAL

(J. HUBIČKA, N. 15)

$\boxed{\text{EXAMPLE}}$ $\mathrm{FORB}_{\mathrm{HOM}}$ ()

PIECES 

FORB ( , )

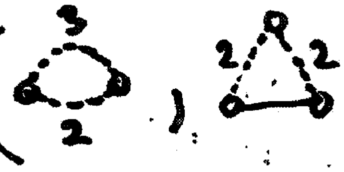
③ FORBIDDEN HOMOMORPHISMS FROM AN INFINITE REGULAR FAMILY $\mathcal{F}$ WHICH IS LOCALLY FINITE

RAMSEY LIFT = ORDERING + MAXIMAL

(J. HUBIČKA, N. 15)

$\boxed{\text{EXAMPLE}}$ $\mathrm{FORB}_{\mathrm{HOM}}$ ()

PIECES 

FORB ()

$\mathrm{FORB}_{\mathrm{HOM}}$ () NOT RAMSEY

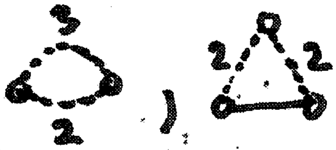
③ FORBIDDEN HOMOMORPHISMS FROM AN INFINITE REGULAR FAMILY $\mathcal{F}$ WHICH IS LOCALLY FINITE

RAMSEY LIFT = ORDERING + MAXIMAL

(J. HUBIČKA, N. 15)

$\boxed{\text{EXAMPLE}}$ $\mathrm{FORB}_{\mathrm{HOM}}$ ()

PIECES 

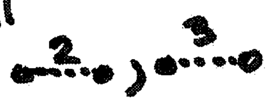
FORB ()

$\mathrm{FORB}_{\mathrm{HOM}}$ () NOT RAMSEY

$\overrightarrow{\mathrm{FORB}_{\mathrm{HOM}}}$ ( ,  , )

RAMSEY

$\cap$

REL (E, )

(4) METRIC SPACES

(a) FINITE METRIC SPACES

RAMSEY LIFT = LINEAR ORDER

N. 05

n

(4) METRIC SPACES

(a) FINITE METRIC SPACES

RAMSEY LIFT = LINEAR ORDER

N. 05

(b) GRAPHS WITH ISOMETRIC EMBEDDINGS

RAMSEY LIFT = LINEAR ORDER

DELLAMONICA, RÖDL 12

n

4 $\boxed{\text{METRIC SPACES}}$

a FINITE METRIC SPACES

RAMSEY LIFT = LINEAR ORDER

N. 05

b GRAPHS WITH ISOMETRIC EMBEDDINGS

RAMSEY LIFT = LINEAR ORDER

DELLAMONICA, RÖDL 12

c S - METRIC SPACES

(SPACES WITH DISTANCES IN S)

$\boxed{\text{THM}}$ FOR S THE FOLLOWING IS EQUIV.

1. FINITE CONVEXLY ORDERED S-METRIC SPACES ARE RAMSEY
2. THERE EXISTS S-URYSOHN SPACE

HUBIČKA, N. 15+ (USING SAUER 12)

d) ALL ULTRAHOMOGENEOUS METRIC SPACES (CHERLIN LIST)

HAVE RAMSEY LIFT

(ARANDA, BRADLEY-WILLIAMS, HUBIČKA, KARAMANLIS, KOMPATSCHER, KONEČNÝ, PAWLIUK)

A MASTER THEOREM

(HUBIČKA, N. 16)

$\mathcal{R}$ RAMSEY CLASS, $\mathcal{K} \subseteq \mathcal{R}$

SATISFIES:

- $\mathcal{K}$ HEREDITARY
- $\mathcal{K}$ CLOSED ON STRONG AMALGAMATION
- ALL STRUCTURES IN $\mathcal{R}$ WHICH CANNOT BE COMPLETED IN $\mathcal{K}$ ARE LOCALLY FINITE.

THEN $\mathcal{K}$ IS RAMSEY CLASS.

A MASTER THEOREM

(HUBIČKA, N. 16)

$\mathcal{R}$ RAMSEY CLASS, $\mathcal{K} \subseteq \mathcal{R}$

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THEN $\mathcal{K}$ IS RAMSEY CLASS.

(LOCAL FINITE: FOR SOME f $\exists\mathcal{F}$

$F \not\to A \Rightarrow \exists F' \in \mathcal{F}$ $\left(|F'| \leq f(|A|) \right)$
$F' \not\to A$)

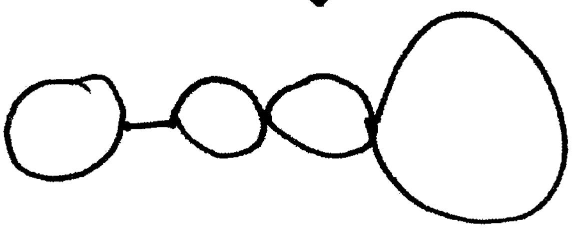
ALSO GENERAL RESULTS FOR STRUCTURES WITH CLOSURES ($\sim$ ALGEBRAIC RANK)

u

$\boxed{\text{EXAMPLE}}$

$\mathrm{FORB}_{\mathrm{MONO}}(\{F\})$ UNIVERSAL

$\Updownarrow$ CHERLIN CONJ.

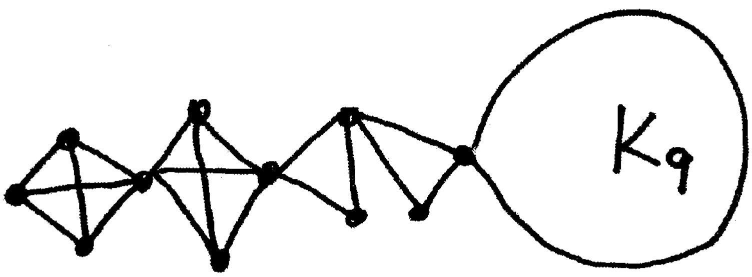


CHAIN OF COMPLETE GRAPHS

$\boxed{\text{THM}}$ ALL CHERLIN CLASSES HAVE RAMSEY LIFT.

(HUBIČKA, N. 16)

FOR EXAMPLE:



NO CHARACTERISATION

BUT

(SURPRISING) RICH

VARIETY

AND

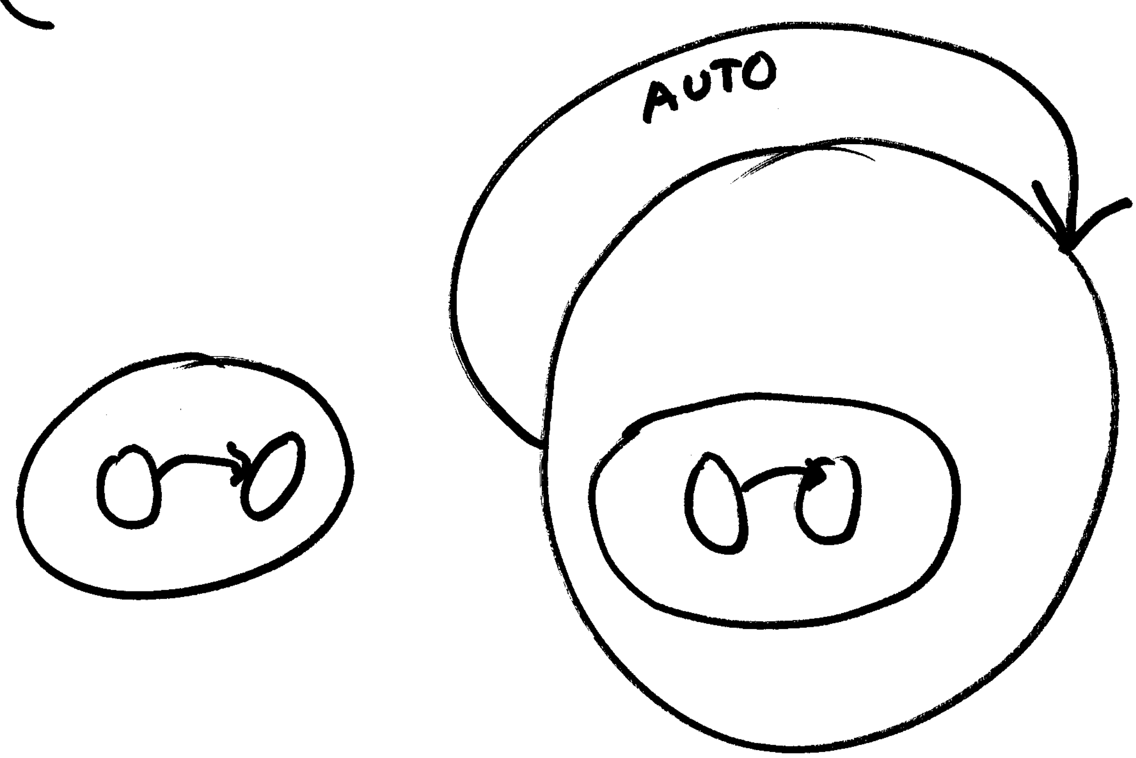
VERSATILITY OF

RAMSEY CLASSES

CONCLUDING REMARKS

SIMILAR RESULTS FOR EXTENSION PROPERTY FOR PARTIAL ISOMORPHISMS } EPPA

(HRUSHOVSKI PROPERTY)



$\boxed{\text{THM}}$ (EVANS, HUBIČKA, N. 17)

LET L BE LANGUAGE SUCH THAT EVERY FUNCTION $F \in L$ IS UNARY. THEN EVERY FREE AMALGAMATION CLASS $\mathcal{K}$ OF L-STRUCTURES HAS EPPA.

(EXTENDS HODKINSON-OTTO, HERWIG-LASKAR)

BINARY?

DO STEINER SYSTEM HAVE EPPA?


Placed Image

DOCCOURSE
"SPARSITY"

NOV 4 — DEC 15
2018

AN INTENSIVE PROGRAM
FOR STUDENTS AND POSTDOCS

LECTURES & EXERCISES

SPEAKERS

I. ADLER, B. SULLIVAN, F. REIDL,
MI. PILIPCZUK, S. SIEBERTZ,
P. SIMON, P. OSSONA DE MENDEZ,
D. KRÁĽ, ...

DOCCOURSE@IUUK.MFF.CUNI.CZ

THANK YOU FOR
YOUR ATTENTION